Exercises in canine physical rehabilitation: range of motion of the forelimb during stair and ramp ascent

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OBJECTIVES: To evaluate overall joint range of motion of the forelimb in healthy dogs ascending stairs compared with incline slope walking.

METHODS: Normal canine forelimb kinematics (range of motion, flexion and extension) were compared during ascent of stairs or a ramp, and compared to unimpeded trotting on a flat surface. Eight adult dogs with no evidence of orthopaedic or neurological lameness were assessed using a 2-dimensional kinematic system as they walked up a custom built ramp and stairs.

RESULTS: In healthy dogs, ramp and stair ascent consistently had greater range of motion compared to trotting on a flat surface, and ramp ascent had significantly greater range of motion compared to stair ascent (P<0.05). Shoulder flexion and extension, elbow extension and carpal flexion were all significantly greater while ascending the ramp compared to stairs. Shoulder extension on the flat was significantly greater than while ascending stairs.

CLINICAL SIGNIFICANCE: When planning physical rehabilitation exercises following injury to the forelimb, stair and ramp ascent may be considered, as both augment range of motion of joints. Ramp ascent provides the greatest increase in range of motion of forelimb joints.

INTRODUCTION

Forelimb injuries, and neurological and orthopaedic conditions are common sources of gait abnormalities in dogs. Successful recovery from neurological or orthopaedic injury to the forelimb may be enhanced with the use of physical rehabilitation (Canapp et al. 2009, Davidson et al. 2005, Hamilton 2004). The goal of physical rehabilitation is to improve or maintain function, while reducing pain. Increasing overall joint range of motion (ROM) of affected joints may require the use of activities other than walking or trotting on a level surface (Marsolais et al. 2003). Recovery from many of these injuries, such as shoulder and elbow luxation, may benefit from active and passive ROM (Davidson et al. 2005). Use of inclined surfaces and stairs for forelimb injuries has been described, but little research has been done to evaluate the effects of each.

ROM is crucial in order to enhance or maintain joint function (Hamilton 2004, Saunders et al. 2005). In addition to primary conditions of the forelimb, joints of the forelimb may also compensate for conditions affecting the hindlimb because of weight shifting from the pelvic limbs to the forelimbs. This may lead to chronic forelimb lameness over time. Thus, activities that affect ROM are of particular importance to the physical rehabilitation practitioner.

Kinematic evaluation provides an objective way of measuring motion by describing joint angles, velocity, acceleration and stride length. Several systems exist to collect 2- or 3-dimensional (2D, 3D) data. In humans, the use of 3D analysis has been recognised as the standard method of gait analysis (Kim et al. 2008). However, a recent study evaluating the difference between the two systems suggests that 2D systems can provide accurate and repeatable data.
when analysing canine pelvic limbs in the sagittal plane at a walk (Kim et al. 2008, Feeney et al. 2007). Joint angle changes from a 2D system can be reported in various planes, such as linear, coronal and diagonal (Durant et al. 2011, Kim et al. 2008), however, measurements in the transverse and frontal planes have not been studied extensively. Thus, output from either 2D or 3D systems can be used to evaluate joint ROM in dogs.

ROM in joints of the forelimb has not been evaluated as thoroughly as the hindlimb in dogs. A recent study evaluated normal forelimb walking on a level surface compared to uphill and downhill walking on a treadmill, and to low cavaletti rails (Holler et al. 2010). They concluded that walking on a treadmill at a grade or incline of 11% (angle of inclination 6-3°) had no significant effect on the forelimb joint ROM when compared to walking on a level surface. However, it is possible that altering the incline could result in a significant change in ROM. Perhaps by using a steeper slope, or, by using stairs instead of a flat ramp, ROM could be increased significantly compared to activity over level surfaces. In dogs, kinematic analysis has been used to describe ROM of the hindlimb in normal and in cranial cruciate deficient stifles (Marsolais et al. 2003), as well as in dogs with hip dysplasia (Bockstahler et al. 2007) and elbow disease (Burton et al. 2008). It has also been used to describe ROM of pelvic limbs of normal dogs during different activities such as swimming (Marsolais et al. 2003), and descent of stairs and ramps (Durant et al. 2011, Millard et al. 2010).

When reviewing data concerning inclined surfaces, it is important to clarify definitions pertaining to the incline. The slope is also the tangent of the angle of elevation. The inverse tangent of the grade, or percent inclination as given by a treadmill, will be the tangent of the angle of elevation. The inverse tangent of the grade, or percent inclination, can be used interchangeably, but are not the same as slope or the angle of elevation.

Recently, Durant et al. (2011) evaluated motion of the major joints of the pelvic limb during ascent of stairs and ramp compared to a flat surface. They concluded that dogs undergo greater hindlimb ROM while ascending stairs compared to a ramp and flat surface. However, the ramp angle was not as steep as the stairs. This suggests that steeper angles of incline may be required to significantly change the ROM in the pelvic limb from that on a flat surface or stairs, and similar factors may exist regarding exercises for forelimb motion. This information may be useful, particularly because stair exercises are commonly recommended in dogs for rehabilitation (Durant et al. 2011). However, it is important to realise there are significant differences in forelimb and hindlimb weight distribution. It is a well-accepted fact that the forelimbs bear roughly 60% of a dog’s individual bodyweight, whereas the hindlimbs bear 40% during walking on a flat surface (Budsberg et al. 1987). At a minimum, bodyweight and conformation make significant contributions to weight distribution in individual dogs (Voss et al. 2011). Information regarding forelimb weight distribution and motion is sparse and may be beneficial in implementing clinical activities to enhance or maintain ROM of the forelimb following injury in dogs.

The purpose of the study reported here was to evaluate the shoulder, elbow and carpal joints of normal dogs during ascent of stairs and a ramp of equal inclination, and trotting on a level surface. It was hypothesised that there would be a significant increase in ROM with ascent of both inclined surfaces as compared to trotting on a flat surface, and that forelimb motion would not be significantly different between ascent of an inclined ramp or stairs.

**MATERIALS AND METHODS**

Eight female adult hound-type mixed breed dogs were included in the study. Bodyweight ranged from 21-3 to 24-5 kg. At the time of the study, all dogs were approximately five years of age. All dogs were healthy as determined by haematologic and clinical chemistry data. In addition, all dogs were deemed sound by thorough physical, orthopaedic and neurological examinations before the study. The study was approved by the University of Tennessee’s animal care and use committee.

Forelimb joint motion in the sagittal plane was assessed while jogging and during ascent up a set of standard stairs and a ramp (Fig 1). The stairs had an angle of inclination of 35 degrees (70% grade). The dimensions for each of the four steps were height 17-78 cm, length 25-4 cm and width 91-4 cm. The stairs served as the base for the ramp, which therefore also had a mean angle of inclination of 35 degrees (70% grade). The ramp was fashioned by covering the staircase with a platform and commercial-grade carpet. Dogs were accustomed to ascent of the stairs and ramp before entering the study. The same handler was used for all trials.

Kinematic analysis was performed using a 2D digital capture system (Peak Motus). Hair was clipped and dogs were outfitted with spherical, reflective markers (1-3 cm in diameter) on the skin overlying the proximal spine of the scapula, greater tubercle of the humerus, lateral epicondyile of the humerus, ulnar carpal bone and the head of the fifth metacarpal bone. Digital, infrared cameras (Phillips Electronics) were arranged in a semi-circular pattern approximately 4 m from the recording area. The system was calibrated at the beginning of each study using a standard calibration wand.

![FIG 1. Replication of custom stairs with individual step dimensions of 25-4 cm×91-4 cm×17-8 cm. (reprinted with permission from Durant et al. 2011)](image-url)
Successful trials included those in which the dog ascended the ramp or staircase at a natural walking pace. Five successful trials of stair and ramp ascent were recorded. For each joint, extension angles, flexion angles and overall joint ROM were determined in the sagittal plane. ROM was equal to the difference between maximum joint extension and maximum joint flexion during each trial.

Trotting data were subsequently collected over a flat surface. Acceptable velocity was between 1.7-2.1 m/s and acceleration or deceleration was less than or equal to ±0.5 m/s². Five trials were obtained and averaged for each full gait cycle.

Data were assessed for normality using the Shapiro–Wilk test. All variables were normally distributed; therefore mean and standard deviation (sd) were reported. For each joint, ROM, flexion and extension angles were compared among stairs, ramp and a flat surface using repeated measures ANOVA followed by pairwise comparisons between surfaces. Ninety-five percent confidence intervals were plotted to quantify the uncertainty of estimation. Statistical significance was defined as P<0.05.

**RESULTS**

**Shoulder**

There was a significant difference in peak flexion between the ramp (mean 85.3°; sd 20.5°) and stairs (mean 105.8°, sd 10.1°), with greater flexion occurring while ascending the ramp (Fig 2). Flexion while ascending the ramp was significantly greater than while trotting on a flat surface (mean 119.3°, sd 4.6°). Shoulder peak extension on the ramp (mean 151.8°, sd 12.8°) was significantly greater than trotting on a flat surface (mean 137.9°, sd 3.6°). Shoulder extension trotting on a flat surface was significantly greater than ascending stairs (mean 126.0°, sd 8.6°, P<0.01). However, shoulder extension while ascending the ramp was significantly greater than while ascending the stairs and trotting. Shoulder ROM was significantly greater while ascending the ramp (mean 66.5°, sd 13.3°) when compared to stairs (mean 20.2°, sd 5.3°) or trotting on a flat surface (mean 18.6°, sd 2.7°). However, there was no significant difference in ROM between the stairs and flat surface trotting.

**Elbow**

Elbow flexion while ascending both the ramp and stairs was significantly greater than trotting on the flat (mean 93.6°, sd 10.9°) (Fig 3). Although peak elbow flexion was greater during ascent of the ramp (mean 45.7°, sd 8.4°) compared to stairs (mean 57.0°, sd 8.4°), this difference was not significant. Extension for both the ramp (mean 156.6°, sd 10.8°) and stair ascent were both significantly greater than for trotting (mean 139.6°, sd 6.3°), and elbow extension was significantly greater while ascending the ramp than the stairs (mean 149.0°, sd 5.5°). Elbow ROM was also significantly greater while ascending the ramp (mean 110.9°, sd 13.1°) compared with the stairs (mean 92.0°, sd 7.2°). Ramp and stair values for ROM of the elbow were significantly...
greater when compared to trotting on a flat surface (mean 46-0°, sd 6-2°).

**Carpus**

Carpal flexion was greater while ascending stairs (mean 68-1°, sd 14-0°) and the ramp (mean 55-6°, sd 22°) when compared to trotting on a flat surface (mean 83-9°, sd 23-5°) (Fig 4), and flexion while ascending a ramp was greater when compared to stairs. Carpal extension was significantly greater for both stair (mean 171-0°, sd 3-1°) and ramp (mean 172-5°, sd 4-1°) ascent when compared to trotting on a flat surface (mean 160-8°, sd 5-8°). However, there were no differences in extension between stair and ramp ascent. Carpal ROM was significantly greater while ascending the ramp (mean 136-9°, sd 20-4°) compared to stairs (mean 102-9°, sd 12-3°). Carpal ROM was significantly greater for both stair and ramp ascent compared to trotting (mean 76-9°, sd 24-0°).

**DISCUSSION**

The results of this study indicate that normal dogs achieve greater overall forelimb joint ROM while ascending stairs and ramps compared to trotting on a flat surface. In addition, ROM was greater while ascending a ramp when compared to stairs. These differences were in large part due to significant increases in both flexion and extension of each joint. As anticipated, the most obvious differences were those comparing ramp or stairs to trotting over a flat surface.

The data collected in this study differ from those obtained in a recent study evaluating ROM parameters in the forelimb over flat and inclined surfaces (Holler et al. 2010). In that study, no significant differences were found comparing motion of the forelimb on an incline to a flat surface. An important difference between that study and the present one is the angle of inclination of the ramp. In the referenced study, the angle of inclination of the surface was 6-3 degrees, while the angle of inclination here was 35 degrees. Thus, collectively these studies suggest that an inclined surface greater than 6-3 degrees may result in increased forelimb joint angles. However, it is not clear at which angle beyond that the forelimb joint angles increase significantly.

Another possible reason for the discrepancy is related to the study dogs. In the referenced study, eight client-owned dogs of different breeds with a bodyweight of 23-6 ±4-6 kg were enrolled. The dogs in this report were eight hound-type dogs weighing 22-13 ±1-41 kg. Other workers have suggested that when collecting kinetic data, dogs of different breeds may not be comparable to each other and that group comparisons should not be made among dogs of different bodyweight and conformation (Voss et al. 2011). It is also possible that even dogs of the same breed, but of significantly different size or bodyweight would be different. It is not known what the effect of bodyweight and body conformation on kinematic variables is, but it seems plausible that changes in joint angles during gait are a function of body conformation.

The reason for the increased motion when ascending the ramp compared to stairs is unclear. A recent study evaluated the difference in pelvic limb joint motion while descending a ramp and continuous slope (Millard et al. 2010). The authors concluded that pelvic limb joints of normal dogs achieved different ROM during descent of stairs and an equivalent ramp. In contrast to the results presented here, they found that greater active ROM was achieved in each joint of the pelvic limb during stair descent. The authors speculated that the reason for such differences in ROM is related to the dogs’ stride length. While walking down a ramp, dogs can adjust their stride length as compared with travelling down stairs, which requires moving the limb a fixed distance. Although stride length was not measured in this study, the same speculations regarding stride length changes during stair and ramp descent can be made regarding uphill climbing of stairs and a ramp. Ascending a ramp may allow for an extended ROM of all joints, but in particular the shoulder, because of less restriction of stride length.

Forelimb lameness, especially diseases of the shoulder and elbow, are common and often benefit from physical rehabilitation following injury or surgery (Davidson et al. 2005). Depending on the nature of the injury, it may be advisable to either limit or enhance ROM. For example, a common injury of sporting dogs is sprain of the medial glenohumeral ligament, for which surgical treatment may not be an option (Marcellin-Little et al. 2007). Early rehabilitation for this condition may include rest of the affected joint. However, ROM exercises are ultimately required to restore the joint to normal function. The data of this study may provide useful information to guide the development of physical rehabilitation protocols for various conditions, which may benefit from undergoing activities that aim to increase or maintain ROM.

Stairs and inclined surfaces have not only been employed to increase the ROM of joints they also have been used as methods of strengthening the pelvic limb muscles after injury or disuse (Millis 2004). Although this study was not designed to identify challenged muscle groups, one can speculate that certain muscle groups are strengthened when ascending stairs or inclined surfaces. In a study by Durant et al. (2011), it was speculated that an increased ROM may have an effect on certain muscles of the pelvic limb while ascending stairs. The same may be true of the forelimb, whereby the main extensors of the shoulder and elbow have the greatest influence on ROM. However, future research in this area is warranted.

There were several limitations to this study. The small and homogeneous sample size used may make translation of the information to dogs of different bodyweight and conformation, as well as dogs with lameness of the forelimb, difficult. It is possible that ROM would be different in breeds of different build or size (Kim et al. 2011). One could speculate that results may be more variable with stairs as compared with the ramp, because of the discrete distance of the step requiring greater relative limb excursion in small breeds as compared with giant breeds. A recent study speculated that with a ramp, dogs can adjust their stride length with decline walking, whereas they must move the limb a fixed distance when negotiating stairs (Millard et al. 2010).
Similarly, the dogs in this study may have made adjustments to stride length while ascending the ramp. Proportionally, stride length and joint motion would likely be similar among breeds of different sizes while ascending a ramp of equal slope.

Finally, this study evaluated only one angle of inclination. It may be worthwhile to compare several different inclinations in one study to evaluate the impact of variations in angle. It is possible that there is a certain cutoff, high or low, above or below which changes in inclination have no further effect on joint motion. Recommendations cannot be made on the exact inclination of ramp incline that would be clinically useful for physical rehabilitation of dogs. However, the angle of inclination of the stairs was similar to that found in an average household. It is known that changes in weight shift occur in the forelimbs during activities that change the centre of gravity (Voss et al. 2011). Propulsion from the hindlimbs is the predominant force during incline ascent and braking of the forelimbs is predominant in stair descent. Therefore, evaluating forelimb ROM during stair and incline descent is also warranted.

Future studies are warranted to evaluate the usefulness of these activities in dogs with conditions of the forelimb. The differences in ROM may be less when motion is limited because of disease or pain, especially for ascending a ramp where an individual could adjust the stride length if discomfort exists. It would be helpful to determine the exact angle of inclination required to significantly increase ROM.

On the basis of the results of the study reported here, it is evident that ramp and stair ascent may elicit greater ROM of the joints in the forelimb as compared to trotting over ground. This information may be useful when developing physical rehabilitation protocols following injury or surgery to the forelimb. This information may be used in the design of physical rehabilitation protocols that are focused on maintenance or enhancement of joint angles.

References


